

1 ACTUATING MECHANISM

2

3 The present invention relates to plugs used in oil and
4 gas wells and in particular, though not exclusively, to
5 an actuating mechanism which provides for controlled
6 opening of a plug.

7

8 During the lifetime of an oil/gas production well,
9 various servicing operations will be carried out to the
10 well to ensure that the efficiency and integrity of the
11 well is maximised. This would include; a full work over,
12 surface well-head tree change, side tracking or close
13 proximity drilling operations. To allow any of these
14 operations to be done safely and to accommodate
15 verification pressure tests from surface, it is necessary
16 to install a plug (or plugs) into the production tubing
17 to create a barrier to both test against and provide
18 isolation from the production zones.

19

20 These plugs are typically installed/retrieved from the
21 well bore by either wire line or coiled tubing methods.
22 Wire line and coiled tubing operations however, can be
23 time consuming and risky depending on the application,

1 and are generally kept to a minimum where possible. When
2 retrieving plugs it is necessary to equalise pressure
3 above and below prior to unlocking and removal - this
4 often involves an extra intervention run to initiate
5 equalisation prior to retrieval.

6

7 One type of plug developed to remove the requirement for
8 intervention is referred to as a pump open plug. This
9 device is equalised by applying pressure to the tubing
10 above the plug to a pre-determined value. This causes a
11 specially rated shear pin to fail, actuating the device
12 to communicate pressure between the tubing above and
13 below the plug. Retrieval of the plug can then commence,
14 or the plug left in situ and the well produces through
15 the now open plug. This is a simple design which can be
16 equalised remotely by pressure from the surface. It can
17 also handle over balanced situations i.e. the pressure
18 below the plug is always less than that above due to the
19 hydrostatic weight of fluid above being greater than the
20 zonal pressure below the plug.

21

22 However, this plug does have a number of disadvantages,
23 namely that it does not allow for a full pressure test of
24 the production tubing above the plug as the shear pin
25 rating inherently has to be less than the production
26 tubing's pressure rating. There is also a need to know
27 what the expected pressure below the plug will be prior
28 to opening as this is important when rating the shear
29 pin. Additionally, the over balance conditions
30 permanently load up the shear pin. Shear pins are
31 inherently difficult to manufacture accurately and the
32 shear pin used cannot be tested prior to installation.
33 When the shear pin fails during opening operations the

1 pressure can surge into the zonal formation causing
2 formation damage within the well.

3

4 Pressure cycle plugs have also been developed. Such
5 designs are those disclosed in GB 2,281,752 and EP
6 0,485,243. These are generally referred to as pressure
7 cycle plugs. In such devices the pressure is equalised
8 by applying, from surface, a predetermined number of
9 pressure cycles (pressure up-bleed off). The actual
10 value of pressure applied is less important than that of
11 the pump open plug, it equivalently just needs to be more
12 than the pressure below the plug. During each cycle
13 applied, the equalisation mechanism with the device moves
14 incrementally typically via a ratchet. On the last cycle
15 the mechanism will finally move to a position that will
16 allow communication to occur between the tubing above the
17 plug to that below. Again retrieval of the plug can then
18 commence, or the plug left in situ and the well produced
19 with the now open plug. These plugs are advantageous in
20 that the pressure can be equalised remotely from the
21 surface. The value of the pressure applied is less
22 critical than that needed for operating a pump open plug
23 and the number of pressure cycles can be pre-set before
24 the plug is installed, to allow enough scope to do all
25 the pressure testing etc prior to opening. The plug will
26 open during the bleed off phase of the pressure cycle and
27 thus pressure surges to the formation are minimised. The
28 tubing above the plug can be tested to the maximum
29 pressure rating and then cycled open to a lower pressure.

30

31 While the pressure cycle plug has these advantages, it
32 also has a number of disadvantages. A major disadvantage
33 is that by virtue of the fact that a predetermined amount

1 of cycles have to be undertaken before opening, this can
2 be restrictive in well operations. Often during surface
3 operations, pressures may be applied inadvertently to the
4 tubing and it becomes confusing as to whether they
5 constituted a cycle or not, therefore it becomes less
6 clear how many cycles are left to open the plug. In
7 order to operate the plug a knowledge of the pressure
8 below the plug is required. Because the plug opens
9 during bleed-off, it is not easy to tell if the plug was
10 closed or open until the next cycle is applied.
11 Therefore it is never clear if the plug is really closed
12 without using up another cycle. Shock loading during
13 installation of the plug can cause the internal mechanism
14 to incrementally move, thus using up some cycles without
15 knowledge by the operator. The internal mechanisms are
16 not particularly suitable for use in over balance
17 situation due to the hydrostatic weight of fluid above
18 being greater than the zonal pressure below the plug.

19

20 It is an object of at least one embodiment of the present
21 invention to provide a plug for use in an oil or gas well
22 which overcomes at least some of the disadvantages of the
23 prior art plugs.

24

25 It is an object of at least one embodiment of the present
26 invention to provide an actuating mechanism for use in a
27 plug which overcomes at least some of the disadvantages
28 of the prior art plugs.

29

30 According to a first aspect of the present invention
31 there is provided a plug for controlling fluid flow in a
32 well bore, the plug comprising a substantially
33 cylindrical body adapted for location on a work string,

1 the body including a bore through a portion thereof and
2 one or more radial ports for passage of fluid from the
3 bore to an outer surface of the body, an actuating member
4 moveable relative to the body so as to cover the one or
5 more radial ports in a first position and uncover the one
6 or more radial ports in a second position wherein
7 movement of the actuating member is controlled by an
8 actuating mechanism, the mechanism being operable under
9 pressure in the well bore to set the plug in a first
10 natural state wherein the actuating member is in the
11 first position for a pressure under a predetermined
12 pressure range; a second closed state wherein the
13 actuating member is locked in the first position
14 regardless of the pressure; and a third open state
15 wherein the actuating member is moved to the second
16 position on increasing the pressure to the predetermined
17 pressure range and holding the pressure in the range for
18 a predetermined time.

19
20 Thus the plug can only be opened if the plug begins in
21 the natural state, the pressure is brought up to a
22 predetermined range and held in this range for a given
23 time period. The actuating mechanism can be considered
24 as a timed release actuating mechanism. A rapid increase
25 of pressure will merely lock the plug in the closed state
26 and any pressure variation thereafter will hold the plug
27 in the closed state. With the plug 'locked out' pressure
28 testing can advantageously be carried out above the plug
29 in the well bore.

30
31 Preferably the bore provides communication with the work
32 string such that the plug may be operated by pressure
33 applied from a surface of the well bore.

1 Preferably the actuating mechanism is located in the
2 bore.

3

4 Preferably the predetermined range for the pressure is
5 approximately 1200 to 1800 psi.

6

7 Preferably the actuating mechanism comprises one or more
8 pistons operated on by the applied pressure. More
9 preferably the actuating mechanism comprises first and
10 second pistons; the first piston including a damping
11 element for delaying movement of the first piston
12 relative to the second piston under the applied pressure;
13 the second piston acting on a retaining element; the
14 retaining element adapted to hold the second piston in an
15 intermediate position when the applied pressure is within
16 the predetermined range and allow movement of the first
17 piston to a final position; the retaining element
18 allowing the second piston to move to a secondary
19 position when the applied pressure is above the
20 predetermined range; a locking element which prevents
21 movement of the first piston when the second piston is in
22 the secondary position; and a securing element for
23 retaining the actuating member in the first position
24 until released by virtue of the first piston reaching the
25 final position, whereby the actuating member moves to the
26 second position and opens the plug.

27

28 Thus when a pressure is applied the pistons will move. By
29 virtue of the damping element the first piston will move
30 slower than the second piston. When the pressure reaches
31 the predetermined range, the second piston is held in an
32 intermediate position. If the first piston reaches its
33 final position the actuating member will move and the

1 plug will operate. If the pressure increases above the
2 predetermined range before the first piston reaches its
3 final position, the second piston 'locks out' the first
4 piston and the actuating member remains in the first
5 position. Thus holding the pressure in the intermediate
6 range for sufficient time allows the first piston to
7 move from its starting position to its final position
8 without being 'locked-out' and will cause the actuating
9 member to move and open the plug.

10

11 Preferably the first and second pistons include drive
12 faces upon which the applied pressure acts. More
13 preferably the drive faces are substantially conical with
14 apexes directed towards the applied pressure.

15

16 Preferably the drive faces of the pistons are initially
17 located in the bore. Advantageously the pistons are
18 arranged longitudinally to the body. Optionally the
19 pistons are in parallel alignment.

20

21 Preferably the damping element is a fluid metering
22 device. Preferably the fluid metering device comprises a
23 fluid filled chamber through which the first piston
24 passes. Preferably within the chamber a portion of the
25 first piston includes a restrictor to regulate fluid flow
26 between upper and lower compartments of the chamber.
27 Preferably also a portion of the first piston includes a
28 check valve to allow fluid to be selectively moved
29 between the compartments.

30

31 Advantageously a pressure balance piston is located in
32 the chamber. The pressure balance piston may be arranged
33 around the first piston to control the size of the

1 chamber in order to compensate for thermal effects and
2 pressure differences between inside and outside the
3 chamber.

4

5 Preferably the retaining element is a spring. The
6 retaining element may be a leaf spring. More preferably
7 the retaining element is a collet. Preferably the
8 locking element is a sleeve. The retaining element and
9 the locking element may engage to control movement of the
10 pistons.

11

12 Optionally, the actuating mechanism may comprise a
13 pressure sensor located in the bore to measure the
14 applied pressure, a processor programmed to control a
15 motor in response to the pressure wherein operation of
16 the motor causes the required relative movement between
17 the actuating member and the body.

18

19 In this embodiment, the processor is a logic processor
20 programmed to perform the steps required to operate the
21 plug. The mechanism may further comprise a pressure
22 transducer and a battery pack. The motor may drive a
23 ball screw located between the body and the actuating
24 member. The mechanism may also comprise a securing
25 element for retaining the actuating member in the first
26 position.

27

28 Preferably the actuating member is a sleeve. The sleeve
29 may be arranged around a body of the tool.

30

31 Preferably the securing element is one or more locking
32 keys which engage with the sleeve. The keys may engage

1 the sleeve when the sleeve is in the first and second
2 positions to prevent unwanted movement of the sleeve.

3

4 According to a second aspect of the present invention
5 there is provided an actuating mechanism for operating a
6 tool used in a well bore, the mechanism comprising first
7 and second pistons; the first piston including a damping
8 element for delaying movement of the first piston
9 relative to the second piston under an applied pressure;
10 the second piston acting on a retaining element; the
11 retaining element adapted to hold the second piston in an
12 intermediate position when the applied pressure is within
13 a predetermined range and allow movement of the first
14 piston to a final position; the retaining element
15 allowing the second piston to move to a secondary
16 position when the applied pressure is above the
17 predetermined range; a locking element which prevents
18 movement of the first piston when the second piston is in
19 the secondary position; an actuating member whose
20 movement operates the tool; and a securing element for
21 retaining the actuating member in a first position until
22 released by virtue of the first piston reaching the final
23 position, whereby the actuating member moves to a second
24 position and operates the tool.

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27 virtue of the damping element the first piston will move
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29 the predetermined range, the second piston is held in an
30 intermediate position. If the first piston reaches its
31 final position the actuating member will move and the
32 plug will operate. If the pressure increases above the
33 predetermined range before the first piston reaches its

1 final position, the second piston 'locks out' the first
2 piston and the actuating member remains in the first
3 position. Thus holding the pressure in the intermediate
4 range for sufficient time allows the first piston to
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10 faces upon which the applied pressure acts. More
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17 passes. Preferably within the chamber a portion of the
18 first piston includes a restrictor to regulate fluid flow
19 between upper and lower compartments of the chamber.
20 Preferably also a portion of the first piston includes a
21 check valve to allow fluid to be selectively moved
22 between the compartments.

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24 Advantageously a pressure balance piston is located in
25 the chamber. The pressure balance piston may be arranged
26 around the first piston to control the size of the
27 chamber in order to compensate for thermal effects and
28 pressure differences between inside and outside the
29 chamber.

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32 retaining element may be a leaf spring. More preferably
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2 the locking element may engage to control movement of the
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5 Preferably the actuating member is a sleeve. The sleeve
6 may be arranged around a body of the tool. Preferably the
7 securing element is one or more locking keys which engage
8 with the sleeve. The keys may engage the sleeve when the
9 sleeve is in the first and second positions to prevent
10 unwanted movement of the sleeve.

11

12 According to a third aspect of the present invention
13 there is provided a controlling fluid flow in a well
14 bore, the method comprising the steps:

15

- 16 (a) locating a plug in a well bore, the plug including
- 17 an actuating mechanism to operate the plug;
- 18 (b) increasing pressure from a surface of the well bore
- 19 to within a predetermined range; and
- 20 (c) keeping the pressure within the predetermined range
- 21 over sufficient time to cause the actuating
- 22 mechanism to move and open the plug.

23

24 Preferably the plug is according to the first aspect.

25

26 Preferably the method includes the step of applying
27 pressure above the predetermined range.

28

29 Preferably the method includes the step of locking the
30 plug in a closed position in the event that the pressure
31 exceeds the predetermined range.

32

1 The method may then include the step of performing a
2 pressure test above the plug.

3

4 Preferably also the method includes the step of bringing
5 the pressure back down to below the predetermined range
6 to then perform steps (b) and (c) to open the plug.

7

8 It will be appreciated that where reference is given to
9 the terms 'up' and 'down' this is relative and the
10 invention could equally well be applied in deviated or
11 horizontal well bores where the references would convert
12 accordingly.

13

14 Embodiments of the present invention will now be
15 described, by way of example only, with reference to the
16 following drawings of which:

17

18 Figure 1 is a cross-sectional view of plug in parts (a),
19 (b) and (c) according to an embodiment of the present
20 invention, in the natural state;

21

22 Figure 2 is a cross-sectional view of the plug of Figure
23 1 in parts (a), (b) and (c) of the plug in a locked out,
24 closed state;

25

26 Figure 3 (a)-(d) are part cross-sectional views of the
27 plug of Figure 1 illustrating the locking out procedure;

28

29 Figure 4 is a part cross-sectional view through the plug
30 of Figure 1 in the locked out state;

31

1 Figure 5 is a cross-sectional view of the plug of Figure
2 1 in parts (a), (b) and (c) wherein the plug is now in
3 the open state;
4
5 Figures 6 is a part cross-sectional views through the
6 plug of Figure 1 in the open state;
7
8 Figures 7 (a) and (b) are part cross-sectional views of
9 the plug of Figure 1 illustrating the procedure to return
10 to the natural state from the locked out state;
11
12 Figure 8 is a series of schematic cross-sectional views
13 through a plug, illustrating the (a) natural state, (b)
14 closed state and (c) open state, according to a further
15 embodiment of the present invention; and
16
17 Figure 9 is a plot of time against applied pressure for
18 three pressure tests and an opening run.
19
20 Referring initially to Figures 1(a), (b) and (c) there is
21 illustrated a plug, generally indicated by reference
22 numeral 10, according to a first embodiment of the
23 present invention. It will be appreciated that the
24 sections 14, 18, 24 shown in Figures 1(a), (b) and (c) are
25 spliced together to form a single plug where a base 12 of
26 the section 14 meets the top 16 of section 18 and a base
27 20 of section 18 meets a top 22 of section 24. Thus a
28 full plug 10 is illustrated.
29
30 Plug 10 comprises a substantially cylindrical body
31 assembly 26 on which is located an outer sleeve 28. At
32 an upper end 30 of the body 26 there is located a
33 threaded connector 32 for joining the plug 10 to an

1 anchoring device located on a work string (not shown).
2 It will be appreciated by those skilled in the art that
3 such an anchoring device may be a packer or other sealing
4 element such that fluid is prevented from travelling up
5 through the well bore from a location at the plug unless
6 it travels through the plug into the work string.

7
8 Body 26 comprises an upper bore portion 34 for
9 continuance of the bore of the work string. Through the
10 body 26 are arranged four circumferentially spaced radial
11 flow ports 36 a-d. It will be appreciated that the size
12 of these ports may be selected to determine a flow area
13 for fluid from the outer surface 38 of the plug 10 to the
14 bore portion 34 and thereon through the work string.
15 Flow ports 36 are angled downwards to enhance the passage
16 of fluid flow.

17
18 The ports 36 are opened or closed via movement of the
19 outer sleeve 28. Seals 40a,b further prevent any fluid
20 flow between the ports 36 and the outer surface 38 when
21 the sleeve 28 covers the ports 36. Outer sleeve 28 is
22 biased to the open position by virtue of a compression
23 spring 42 located between a shoulder 44 of the body 26
24 and a shoulder 46 on the sleeve 28. A shoulder sleeve 54
25 is located at a base 52 of the outer sleeve 28. The outer
26 sleeve 28 is retained in position by locking keys 48
27 positioned on the body 26 which locate within a groove 50
28 formed at the base 52 of the outer sleeve 28 and the
29 shoulder sleeve 54. It will be appreciated that there may
30 be one or more locking keys 48 arranged circumferentially
31 around the body 26 of the plug 10. On movement of the
32 locking keys 48, the outer sleeve 28 and support sleeve
33 54 can move together on the outer surface 38. Movement is

1 as described hereinafter with reference to the further
2 Figures.

3
4 Arranged axially within the body 26 is a primary piston
5 58. Piston 58 includes a conically arranged face 60 upon
6 which fluid can act. The shape of the face 60 is
7 selected to help allow the piston 58 to return even when
8 sand or other soft debris has settled above. Piston 58
9 thereafter comprises a shaft 59 running through a central
10 portion of the plug 10. Surrounding the shaft 59 is a
11 locking collet 60. Locking collet 60 comprises three
12 dogs 62, although only two are shown in cross-section,
13 which are arranged around the piston 58 while being
14 connected to the body 26. Piston 58 thereafter passes
15 into a metering chamber 64.

16
17 Within the metering chamber 64, a portion 66 of the shaft
18 59 is broadened in circumference so that the outer wall
19 68 of the portion 66 touches the inner wall 70 of the
20 chamber 64. Seals 72 prevent the passage of fluid
21 through the chamber around the piston 58 at this point.
22 Chamber 64 is filled with hydraulic fluid 78. A fluid
23 restrictor 74 and a check valve 76 are arranged
24 longitudinally through the portion 66. The fluid
25 restrictor 74 and check valve 76 control the passage of
26 fluid flow within the chamber 64 between an upper
27 compartment 65a and a lower compartment 65b. As piston 58
28 moves downwards, fluid flows through restrictor 74 and
29 dampens the movement of the piston 58.

30
31 While the restrictor 74 and valve 76 are illustrated at
32 an angle to a central axis through the plug, it will be
33 appreciated that they could be arranged parallel to the

1 axis. In this way they may be independently supported on
2 the shaft 59.

3

4 Located in the upper compartment 65a of the chamber 64 is
5 a balance piston 80. Piston 80 surrounds the shaft 59 and
6 contacts the wall 70 of the chamber 64. O-rings 82
7 provide a seal against the wall 70 while allowing the
8 piston 80 to be free to move within the chamber 64 in
9 either direction to compensate for thermal effects and
10 pressure differences between the inside and the outside
11 of the chamber 64. Thus the balance piston 80 ensures
12 that the behaviour of the fluid restrictor 74 and check
13 valve 76 is uniform regardless of the operating
14 temperature and pressure in the plug 10.

15

16 The primary piston 58 exits the chamber 64 and is
17 terminated after a short length by a bleed screw 90
18 arranged in its base. The bleed screw 90 provides access
19 through the piston 58 to the chamber 64 so that hydraulic
20 fluid 78 can be introduced and bled off. At its base,
21 the primary piston 58 is connected to a support sleeve
22 86. The support sleeve 86 abuts the rear of the locking
23 keys 48 and pushes them in to the grooves 50. At a base
24 of the support sleeve 86 is positioned a return spring 92
25 which biases the piston 58 towards the top 30 of the plug
26 10.

27

28 Located adjacent and in parallel to the primary piston 58
29 is a locking piston 94. Piston 94 also has a conically
30 arranged face 96. In an embodiment, the piston face 96
31 may be identical to the face 60 of the primary piston 58.
32 This ensures that the pistons 58,94 will act together
33 when pressure is first applied to their faces 60,96.

1 Piston 94 abuts a locking sleeve 98. On an inner surface
2 100 of the locking sleeve 98 is a longitudinal recess 102
3 in which the dogs 62 of the locking collet 60 may locate
4 to allow them to be in a natural state. At a base 104 of
5 the locking sleeve 98 is shoulder 105 against which is
6 arranged a return spring 106 which biases the locking
7 piston 94 toward the top 30 of the plug 10.

8
9 A secondary collet 108 is arranged around the locking
10 sleeve 98. Located below the collet 108 is a retaining
11 shoulder 110. Opposite and above the retaining shoulder
12 110 is a further retaining shoulder 112 located on the
13 locking sleeve 98. Contained between the retaining
14 shoulders 110,112 is a circumferential key retainer 114
15 biased towards the further retaining shoulder 112 by a
16 return spring 116 abutting the retaining shoulder 110.
17 Keys 118 are mounted on the key retainer 114, protruding
18 toward the collet 108. Excepting the collet 108, these
19 components form an easy return mechanism for the locking
20 piston 94 as will be described hereinafter with reference
21 to the operation of the plug 10.

22
23 A further feature of the plug 10 is a centraliser 120
24 mounted on the outer surface 38 of the body 26 towards
25 the bottom end 56. Centraliser 120 is of known
26 construction providing a plurality of longitudinally
27 arranged blades 122 which can abut walls of the well and
28 ensure the plug 10 is centralised with respect to the
29 well bore.

30
31 In use, the plug 10 is arranged as shown in Figure 1 and
32 as described above. The end faces 60,96 of pistons 58,94
33 locate in the bore 34 at the same horizontal position.

1 The return springs 92, 106, 116 are at maximum extension
2 so the pistons 58,94 are fully biased. The portion 66 of
3 the primary piston 58 is located centrally in the chamber
4 64. The support sleeve 86 is supporting the locking keys
5 48 into grooves 50. Outer sleeve 28 is therefore locked
6 in a closed position with the ports 36 covered by the
7 sleeve. In this 'natural' state the plug 10 is connected
8 to an anchoring device as discussed above and run into a
9 well bore.

10

11 When the anchoring device seals off the well bore between
12 the production tubing inner diameter and the plug body
13 26, pressure can be applied to the plug 10 by the flow of
14 fluid downwards through the work string. This applied
15 fluid pressure will act upon the faces 60,96 of the
16 pistons 58,94 uniformly. Locking piston 94 will travel
17 downwards faster than primary piston 58. This is because
18 as primary piston 58 moves downwards, hydraulic fluid 78
19 must pass through the restrictor 74 and thus passage of
20 the piston 58 is dampened.

21

22 If the pressure applied is sufficient to move the locking
23 piston 94 downwards until the base 105 meets a top 124 of
24 the chamber 64, before the portion 66 of the primary
25 piston 58 reaches the bottom 126 of the chamber 64, the
26 plug 10 moves to a locked position. This is illustrated
27 in Figure 2.

28

29 Reference is now made to Figure 3 of the drawings which
30 illustrates the key 118/collet 108 interaction which
31 locks the primary piston in position. Like parts between
32 the Figures have been given the same reference numerals
33 to aid clarity. Figure 3(a) shows the relationship of the

1 components in the natural state. Key retainer 114 is
2 biased against shoulder 112 by return spring 116. The
3 keys 118 are free to move along an inner surface 128 of
4 the collet 108. Pressure applied to the piston 94, forces
5 the keys 118 downwards with respect to the collet 108
6 against the spring 116. The keys 118 push the dogs 130
7 of the collet 108 outwards as illustrated in Figure 3(b).
8 Continual pressure moves the keys 118 under the dogs 130
9 and downwards until the retainer ring 114 bottoms out on
10 a shoulder 131 located on a mount 132 for the retaining
11 shoulder 110. This is illustrated in Figure 3(c). The
12 keys 118 are prevented from moving toward the top 30 of
13 the plug 10, such as would occur during pressure bleed
14 down, by virtue of the keys 118 meeting the underside 134
15 of the dogs 130. This is illustrated in Figure 3(d).

16

17 Returning to Figure 2, it can be seen that as the
18 retaining ring 114 bottoms out, the dogs 62 engage the
19 primary piston 58, locking it in position. A
20 circumferential lip 136 on the shaft 59 further prevents
21 the primary piston from downward movement by abutting to
22 surfaces 138 of the dogs 62. This is illustrated in
23 Figure 4. It is noted that outer sleeve 28 remains in
24 the same locked position when the primary piston is
25 locked out. Thus the ports 36 remain closed. In this
26 position, pressure testing can be performed above the
27 plug 10 on the work string. Excess pressure applied to
28 the plug 10 from above will merely hold the tool more
29 tightly in the locked position.

30

31 If the applied pressure is raised to within a
32 predetermined range when the plug 10 is run in, the plug
33 can be opened. The predetermined pressure range is set

1 by the strength of the collet 108. Returning to Figure 1,
2 when pressure is applied the two pistons 58,94 move as
3 described above. When the keys 118 reach the dogs 130 of
4 collet 108, they are held there if the pressure is in the
5 predetermined range. The locking piston 94 is thus held
6 at this location as the key retainer 114 abuts the
7 retaining shoulder 112. There is no such restriction on
8 the primary piston 58 and it will travel downwards on its
9 damped path. As long as the pressure is maintained in the
10 predetermined range, after a period of time, the primary
11 piston will reach a final position as illustrated in
12 Figure 6. The period of time is the time it takes to
13 meter the hydraulic fluid 78 through the restrictor 74.
14 This can be set by the size of the restrictor 74, taking
15 note of the damping required to the primary piston 58.

16

17 In a preferred embodiment, the predetermined range is a
18 relatively low pressure of 1200 - 1800 psi and the time
19 period is approximately 10 mins. Thus holding the
20 pressure on the plug 10 to within the predetermined range
21 for the time period allows the primary piston to reach
22 its final position.

23

24 Referring now to Figure 5, the lip 136 of the shaft 59
25 has passed the dogs 62 of the locking collet 60. The dogs
26 62 move outwardly into the groove 102 to allow the piston
27 to pass through unimpeded. The groove 102 locates beside
28 the dogs 62 by virtue of the keys 118 being stopped by
29 the dogs 130 on the collet 108. This is illustrated in
30 Figure 6. The portion 66 has now reached the base 126 of
31 chamber 64. The support sleeve 86 has move downwards to
32 locate a recess 140 of the sleeve 86 behind the locking
33 keys 48. As a result the locking keys 48 move radially

1 inwards a sufficient distance to unlock the outer sleeve
2 28 from the body 26. On release of the sleeve 28, spring
3 42 causes movement of the sleeve 28 downwardly towards
4 the centraliser 120. In the embodiment shown the shoulder
5 54 abuts the centraliser 120 to prevent further passage
6 of the sleeve 28. On moving the sleeve 28 has uncovered
7 the ports 36. Thus the plug is now open and fluid can
8 flow between the work string, bore 34 and the annulus
9 around the plug 10 in the well bore. Fluid flow may be in
10 an uphole or downhole direction dependant on the pressure
11 within the work string and in the annulus.

12

13 To prevent the sleeve 28 from inadvertantly closing over
14 the ports 36, the keys 48 locate into the housing 142 of
15 the spring 42 and abut the shoulder 144.

16

17 While the contact sleeve 87 is illustrated as a single
18 sleeve, in an alternative embodiment this sleeve 87 may
19 be two parallel aligned sleeves such that the friction on
20 the keys 48 is reduce as one sleeve remains stationary
21 while the other slides underneath it to release the
22 collet.

23

24 While the plug 10 can be opened as the pressure is
25 applied, it is more useful to be able to open the plug 10
26 after pressure testing has been completed. In order to
27 move the plug from the locked out position, shown in
28 Figure 2, to the open position, shown in Figure 5, the
29 applied pressure is bled off to return the pistons 58,94
30 to their natural state i.e. Figure 1. Pressure can then
31 be applied as described hereinbefore to open the plug 10.

32

1 On reducing the pressure, from the locked-out position
2 shown in Figure 3(d), the return spring 116 pushes the
3 key retainer 114 toward the top 30 of the plug 10. The
4 keys 118 ride up to an under surface 134 of the dogs 130.
5 The locking piston return spring 106 biases the locking
6 piston 94 towards the top 30 of the plug 10. This moves
7 locking sleeve 98 upwards relative to the key retainer
8 114, and the keys 118 are thus arranged against a
9 narrower portion 146 of the sleeve 98. As a result the
10 keys 118 move radially inwards to clear the dogs 130. The
11 spring 116 pushes the key retainer 114 passed the dogs
12 130. This is as shown in Figure 7(a). Further biasing of
13 the spring 116 causes the keys 118 to move radially
14 outward again as they pass onto the broader portion 148
15 of the sleeve 98. The key retainer 114 then abuts the
16 shoulder 112. This is as shown in Figure 7(b). This is
17 the easy return mechanism which allows the keys 118 and
18 the key retainer 114 to by-pass the collet 108 easily as
19 the pressure is bled off.

20
21 Both pistons 58,94 are now free to move. The return
22 springs 92,106 are designed so that the primary piston 58
23 returns to its first position ahead of the locking piston
24 94. Thus the ports 36 advantageously cannot be opened
25 during bleed down. As the piston 58, moves through the
26 chamber 64, hydraulic fluid passes through the uni-
27 directional check valve 76 to fill the lower compartment
28 65b. The return springs 92,106 have built in
29 precompression to compensate for an overbalance up to
30 2000psi in a preferred embodiment. The plug 10 is now in
31 the natural state and can be opened as described herein
32 with reference to Figure 5.

33

1 An alternative embodiment of a plug, now referenced as
2 500, is illustrated in Figure 8. In this embodiment, the
3 actuating mechanism 502, is now electronic. The plug 500
4 comprises a cylindrical body 526 on which is located an
5 outer sleeve 528. The body includes radial ports 536
6 substantially as described hereinbefore for the plug 10.

7
8 In this embodiment applied pressure now acts on a
9 pressure sensor 540. Via a pressure transducer 542, the
10 applied pressure is transmitted to a logic processor 544.
11 The logic processor 544 is programmed to hold a motor 546
12 in a fixed position, figure 8(a), until the applied
13 pressure is within the predetermined range. When in the
14 range, the logic processor 544 switches on the motor 546
15 to operate. With the motor on, shaft 548 is rotated and
16 with it a ball screw 550 rotates also. Sleeve 552,
17 threaded upon the ball screw 550, is moved downwards
18 relative to the body 26. If at any time the pressure
19 increases above or below the predetermined range, the
20 motor is stopped and then wound in the opposite direction
21 to move the sleeve 552 back to the original starting
22 point.

23

24 If the pressure remains in the predetermined range for a
25 given time period, equated to be the time taken for the
26 motor 546 to move the sleeve 552 over the distance shown
27 between figures 8(a) and 8(b), the plug can open.

28

29 Opening occurs as shown in Figure 8 (c). In this position
30 a recess 554 on the surface of the sleeve 552 is located
31 behind a key 546, on the body 526. The key 546 is drawn
32 radially inwards thus releasing the outer sleeve 528 from
33 the body 526. Spring 558, which had been held in

1 compression between the sleeve 528 and the body 526, then
2 expands. This forces the sleeve 528 downwards relative
3 to the body 526 and the radial ports 536 are opened. The
4 logic processor can also be programmed to reset the plug
5 500 if desired. While the plug 500 could be powered from
6 the well surface , it is more convenient to use a battery
7 pack 560 which can be located in the body 526.

8
9 Reference is now made to Figure 9 of the drawings which
10 shows a graph of applied surface pressure 150 against
11 time 152 for three pressure tests 154a-c and an opening
12 run 156. A zone 158 is marked as a band in the
13 predetermined pressure range. This is called the open
14 zone and any graph which passes, from low pressure,
15 through the zone 158 continuously for the set time period
16 will result in the plug opening.

17
18 Graph 154a shows a steep initial applied pressure which
19 does not remain in the zone 158 for a sufficient time.
20 The graph 154a then levels off to represent a constant
21 high pressure being applied for a pressure test. The
22 pressure is then bled off rapidly.

23
24 Graph 154b has a parabolic increase and decrease of
25 pressure illustrating a sharp pressure test, which does
26 not open the plug.

27
28 Graph 154c illustrates a fast pressure test with an
29 initial rise in pressure above the predetermined range.
30 The pressure is then bled off until it reaches the
31 predetermined range. Once here, although it remains in
32 the zone 158 for the time period, the plug will not open

1 as the pistons were not brought initially back to the
2 natural state.

3

4 In graph 156 the pressure is increased until it is within
5 the zone 158. It is then maintained in the zone 158 for
6 the time period and thus this trace illustrates opening
7 the plug.

8

9 It can be seen from the Figure that it does not matter if
10 the bleed down traces from a higher pressure, fall
11 through the zone 158, as the plug will already be 'locked
12 out' during the pressure up phase.

13

14 The principal advantage of the present invention is that
15 it provides plug which is known to have opened when a
16 pressure is applied in a given range over a set period of
17 time.

18

19 Further advantages of an embodiment the present invention
20 are that it provides a plug which can be opened remotely
21 from the surface; can be tested against any amount of
22 times; can be opened when desired and doesn't require a
23 predetermined number of cycles; can operate in both over
24 and under-balanced conditions; is not susceptible to
25 shock loading or inadvertent pressure spikes due to the
26 damping effects of the fluid metering device; opens at a
27 relatively low pressure to minimise damage to the
28 formation; and removes the uncertainty about whether the
29 plug is open or not.

30

31 It will be appreciated by those skilled in the art that
32 various modifications may be made to the invention
33 hereindescribed without departing from the scope thereof.

1 For example, collets have been used to retain and hold
2 the pistons but leaf springs could equally have been
3 used. The number of locking keys can be varied dependent
4 upon the type of tool being used. Further sleeves could
5 be incorporated, for instance, to encase the locking
6 piston return spring 106 to provide easier assembly and
7 added protection to the spring.

8

9